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SHOCK INITIATION EXPERIMENTS PLUS IGNITION AND GROWTH MODELING OF DAMAGED LX-04 CHARGES

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Abstract. Shock initiation experiments were performed on mechanically and thermally damaged LX-04 (85% HMX and 15% Viton by weight) to obtain in-situ manganin pressure gauge data and run distances to detonation at various shock pressures. The LX-04 charges were damaged mechanically by applying a compressive load of 600 psi for 20,000 cycles, thus creating many small narrow cracks, or by cutting wedge shaped parts that were then loosely reassembled, thus creating a few large cracks. The thermal damaged LX-04 charges were heated to 190˚C for a long enough time for the beta to delta phase transition to occur and then cooled to ambient temperature. Mechanically damaged LX-04 exhibited only slightly increased shock sensitivity, while the thermally damaged LX-04 was much more shock sensitive. The pristine LX-04 Ignition and Growth model, modified only by igniting a larger amount of explosive during shock compression based on the damaged charge density, accurately calculated the increased shock sensitivity of the three damaged charges.

Keywords: Explosive, LX-04, damaged, shock to detonation transition, Ignition and Growth
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INTRODUCTION

Considerable interest exists in studying the shock initiation of damaged HMX (octahydro-1,3,5,7 – tetranitro - 1,3,5,7-tetrazocine) based plastic bonded explosives (PBX's), such as the commonly used LX-04 (85% HMX, 15% Viton by weight). A thorough prior experimental study of the shock initiation of pristine and heated LX-04 [1-2] has provided a great deal of data for the development of Ignition and Growth reactive flow modeling parameters for LX-04. To simulate accident scenarios, damage to LX-04 charges was induced by mechanical and thermal processes. Shock initiation experiments on the mechanically or thermally damaged LX-04 charges containing embedded manganin pressure gauges were then fired. The relative shock sensitivities of the damaged LX-04 charges were compared to that of pristine LX-04 through the use of the Ignition and Growth reactive flow model.

EXPERIMENTAL PROCEDURES

To create damaged LX-04 charges that could be shock initiated, three LX-04 charges were assembled using 90 mm diameter by 5 or 10 mm thick disks stacked to the final thickness with manganin gauge packages inserted between them. One LX-04 charge was mechanically damaged by applying a compressive load of 600 psi for 20,000 cycles, thus creating many small narrow cracks. A second LX-04 charge was machined into several wedge shaped parts that were then loosely reassembled, thus creating a few large "cracks." The third LX-04 charge was thermally damaged by heating to 190°C for a long enough time for the beta to delta phase transition to occur and then cooled to ambient temperature before being fired. Densities of the damaged parts were obtained by either measuring the density (cyclically loaded) or from control samples that were heated and then cooled (thermal damage).

Shock initiation experiments were then performed on the three damaged LX-04 charges using the 101 mm diameter propellant driven gas gun. Aluminum or Teflon flyer plates were accelerated to provide one-dimensional impacts. Embedded manganin gauges yielded pressure histories [3], and run distances to detonation ("Pop Plots") were also measured [4]. This data was then compared to existing data for pristine LX-04 to determine the sensitization effects of damage.

REACTIVE FLOW MODELING

The Ignition and Growth reactive flow model [5] uses two Jones-Wilkins-Lee (JWL) equations of state in the form:

$$p = Ae^{-R_1 V} + Be^{-R_2 V} + \omega C_V T/V \quad (1)$$

where p is pressure in Megabars, V is relative volume, T is temperature, ω is the Gruneisen coefficient, C_V is the average heat capacity, and A, B, R_1 and R_2 are constants. The equations of state are fitted to the available shock Hugoniot and product expansion data. Table 1 contains the LX-04 equation of state and reaction rate constants based on several single and multiple shock experiments [1]. The reaction rate equation is:

$$dF/dt = \underbrace{I(1-F)^b(\rho/\rho_0 - 1 - a)^x}_{0<F<F_{Ig\max}} +$$

$$\underbrace{G_1(1-F)^c F^d p^y}_{0<F<F_{G_1\max}} + \underbrace{G_2(1-F)^e F^g p^z}_{F_{G_2\min}<F<1} \quad (2)$$

where F is the fraction reacted, t is time in μs, ρ is the current density in g/cm^3, ρ_0 is the initial density, p is pressure in Mbars, and I, G_1, G_2, a, b, c, d, e, g, x, y, and z are constants. Table 2 details the Gruneisen parameters used for aluminum and Teflon.

RESULTS/DISCUSSION

Table 3 contains the experimental flyer velocities, impact pressures, and run distances to detonation for the damaged LX-04 shots. Shot 4744 used the thermally damaged LX-04 charge, which had a density of 1.76 g/cm^3 with 8% voids. Shot 4746 used the reassembled wedges of LX-04, which had a density of 1.85 g/cm^3 with 3% voids. Shot 4750 used the mechanically damaged LX-04, which had a density of 1.83 g/cm^3 with 4% voids.

TABLE 1. LX-04 Ignition and Growth parameters.

REACTION RATES	
a=0.0794	x=4.0
b=0.667	y=2.0
c=0.667	z=3.0
d=0.667	F_{igmax}=0.02
e=0.333	F_{G1max}=0.5
g=1.0	F_{G2min} =0.5
I=2.0 x 10^4 μs^{-1}	G_1=220 $Mbar^{-2}\mu s^{-1}$
-	G_2=320 $Mbar^{-2}\mu s^{-1}$

TABLE 2. Gruneisen parameters for inert materials.

INERT	ρ_0 (g/cc)	C (km/s)	S_1	S_2	S_3	γ_0	a
6061-T6 Al	2.703	5.24	1.4	0.0	0.0	1.97	0.48
Teflon	2.15	1.68	1.123	3.98	-5.8	0.59	0.0

TABLE 3. Summary of damaged LX-04 gun shots.

SHOT	IMPACT VELOCITY	INPUT PRESSURE	RUN TO DET.
4744	0.654 km/s Al plates	2.0 GPa	7 mm
4746	0.896 km/s Teflon plates	2.55 GPa	20.5 mm
4750	0.951 km/s Teflon plates	2.85 GPa	17 mm

Figure 1 shows the measured run distances to detonation versus shock pressures for the three damaged LX-04 experiments compared to previous LX-04, PBX 9404, and LX-17 data. The two mechanically induced damaged LX-04 charges had run distances to detonation only slightly shorter than pristine LX-04. The thermally damaged LX-04 charge exhibited a run distance to detonation five times shorter than pristine LX-04 and only twice as long as LX-04 initiated at 190°C. To model these damaged LX-04 shots, only the initial density and the maximum fraction reacted ignited, F_{igmax}, were changed. Shot 4744 used 1.76 g/cm^3 and F_{igmax} = 0.08. Shot 4746 used 1.83 g/cm^3 and F_{igmax} = 0.04. Shot 4750 used 1.85 g/cm^3 and F_{igmax} = 0.03. Figure 2 shows the manganin records for shot 4744, while Fig. 3 shows the corresponding calculations. Figure 4 shows the experimental records for shot 4746, while Fig. 5 shows the pressure calculations. Figure 6 shows the experimental pressures for shot 4750, while Fig. 7 shows the calculated pressure histories. Good agreement between the experimental and calculated run distances to detonation and pressure histories was obtained.

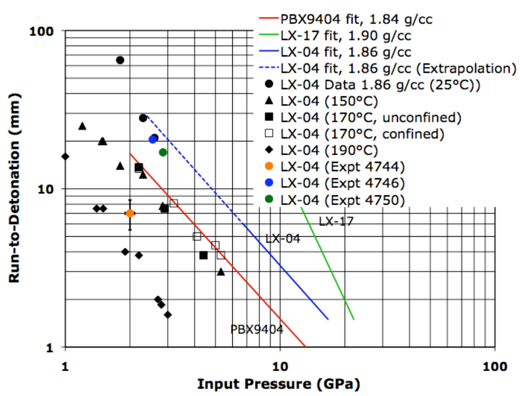

FIGURE 1. Pop-Plot comparing the damaged LX-04 shots with that of previous LX-04 experiments. Note the data line fits for PBX9404, LX-04, and LX-17 are shown for comparison reference.

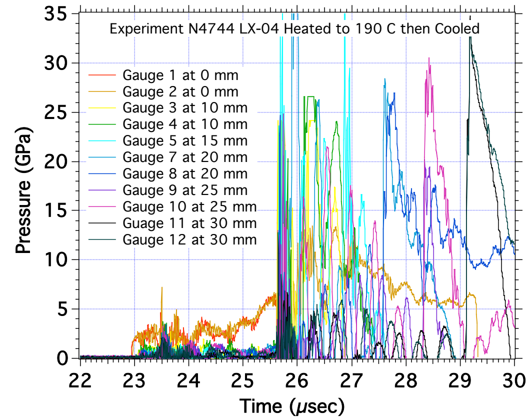

FIGURE 2. Experimental pressures for thermally damaged LX-04 struck by aluminum at 0.654 km/s. Note that the gauge records are extremely "noisy" as a result of the damage present from the phase change.

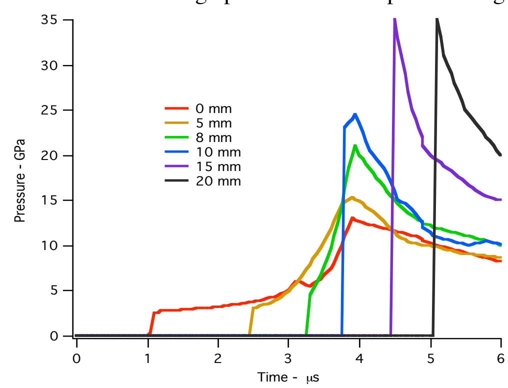

FIGURE 3. Calculated pressures for thermally damaged LX-04 struck by aluminum at 0.654 km/s.

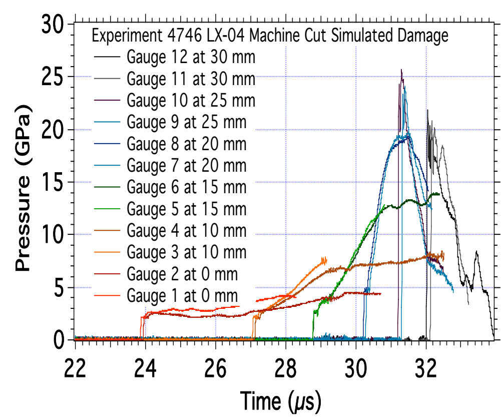

FIGURE 4. Experimental pressure histories for wedges of LX-04 impacted by Teflon at 0.896 km/s.

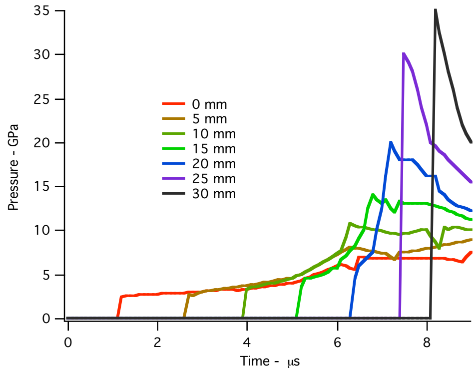

FIGURE 5. Calculated pressure histories for wedges of LX-04 impacted by a Teflon flyer at 0.896 km/s.

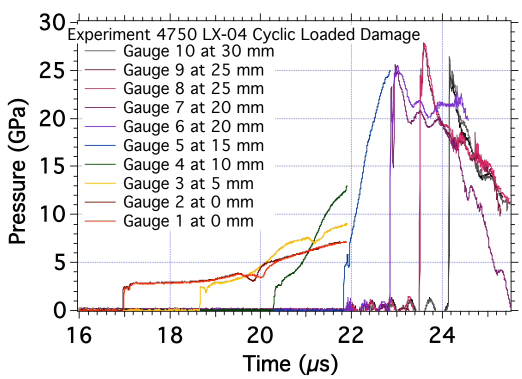

FIGURE 6. Experimental pressures for mechanically damaged LX-04 impacted by Teflon at 0.951 km/s

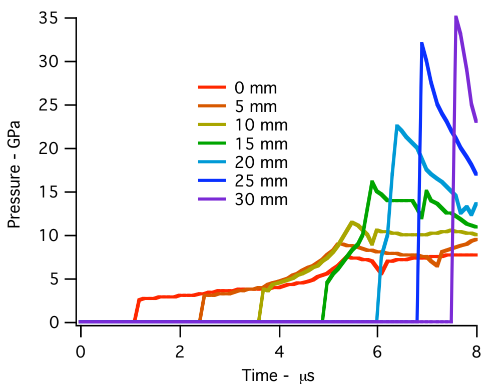

Figure 7. Calculated pressure histories for mechanically damaged LX-04 impacted by a Teflon flyer plate at 0.951 km/s

SUMMARY

Shock initiation experiments on damaged LX-04 showed increased shock sensitivity, especially for the thermal damaged material that underwent the beta to delta phase transition. Only the initial density and the maximum fraction reacted during compression parameter were changed in the LX-04 model to obtain good agreement with the experimental data.

ACKNOWLEDGEMENTS

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